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California Polytechnic
State University
San Luis Obispo, CA 93407

ECONOMICAL GRAPHICS DISPLAY SYSTEM

FOR FLIGHT SIMULATION AVIONICS

FINAL REPORT WITH RECOMMENDATIONS

p. 58

ABSTRACT

DURING THE PAST ACADEMIC YEAR THE FOCAL POINT OF THIS PROJECT HAS BEEN TO ENHANCE THE ECONOMICAL FLIGHT SIMULATOR SYSTEM BY INCORPORATING IT INTO THE AREO ENGINEERING EDUCATIONAL ENVIRONMENT. TO ACCOMPLISH THIS GOAL IT HAS BEEN NECESSARY TO DEVELOP APPROPRIATE SOFTWARE MODULES THAT PROVIDE A FOUNDATION FOR STUDENT INTERACTION WITH THE SYSTEM. IN ADDITION EXPERIMENTS HAD TO BE DEVELOPED AND TESTED TO DETERMINE IF THEY WERE APPROPRIATE FOR INCORPORATION INTO THE BEGINNING FLIGHT SIMULATION COURSE, AERO-418. FOR THE MOST PART THESE GOALS HAVE BEEN ACCOMPLISHED. EXPERIMENTS HAVE BEEN DEVELOPED AND EVALUATED BY GRADUATE STUDENTS. MORE WORK NEEDS TO BE DONE IN THIS AREA. THE COMPLEXITY AND LENGTH OF THE EXPERIMENTS MUST BE REFINED TO MATCH THE PROGRAMMING EXPERIENCE OF THE TARGET STUDENTS. IT HAS BEEN DETERMINED THAT FEW UNDERGRADUATE STUDENTS ARE READY TO ABSORB THE FULL EXTENT AND COMPLEXITY OF A REAL-TIME FLIGHT SIMULATION. FOR THIS REASON THE EXPERIMENTS DEVELOPED ARE DESIGNED TO INTRODUCE BASIC COMPUTER ARCHITECTURES SUITABLE FOR SIMULATION, THE PROGRAMMING ENVIRONMENT AND LANGUAGES, THE CONCEPT OF MATH MODELES, EVALUTION OF AQUIRED DATA, AND AN INTRODUCTION TO THE MEANING OF REAL-TIME.

THIS REPORT INCLUDES AN OVERVIEW OF THE SYSTEM ENVIRONMENT AS IT PERTAINS TO THE STUDENTS, AN EXAMPLE OF A FLIGHT SIMULATION EXPERIMENT PERFORMED BY THE STUDENTS, AND A SUMMARY OF THE EXECUTIVE PROGRAMMING MODULES CREATED BY THE STUDENTS TO ACHIVE A USER-FRIENDLY MULTI-PROCESSOR SYSTEM SUITABLE TO AN AERO ENGINEERING EDUCATIONAL PROGRAM.

DUE TO THE RAPID CHANGING COMPUTER TECHNOLOGY RECOMMEND-ATIONS TO INPROVE THE SYSTEM ARE INCLUDED. THESE RECOMMEND-ATIONS ARE DIRECTED TOWARD THE GRAPHICS PROBLEMS AND THE NEW COMPUTER ARCHITECTURES NOW AVAILABLE AT LOW COST.

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BACKGROUND REVIEW

The basic hardware architecture of the system has not been altered since the last proposal. The simulator is partitioned into three processors. The overall hardware is illustrated in Figure 1. The Intel 286/10 SBC acts as the command executive and graphics high-level controller. The Intel 386/22 SBC handles all real-time computations for control models and simulations. The Intel 186/78 SBC converts the high-level graphics commands into the appropriate graphics primitives and controls the Intel 82720 graphics processor.

Software development for any simulation is still conducted utilizing the operating system RMX86. No attempt has beem made, as yet, to convert to RMX286. At present the Intel 310 development system has .5Mbytes of main memory. RMX286 requires at least .7Mbytes for configuration. Adding another .5Mbytes to the system would solve this problem but would introduce memory partitioning problems as it pertains to MULTIBUS 1. RMX286 operates in protected address mode. This forces a re-partitioning of MULTIBUS space and effects all the processors in the system. Memory strapping options for the 186/78 SBC and the 386/22 SBC are limited. This problem is still under investigation.

Input data to simulation models is currently created by software curve generation. Software modules have been developed this year to allow keyboard input to command the input function and control the type of input, i.e., a doublet, ramp, step, etc. The range of values and sample time are also controlled. Analog I/O is available but memory partitioning must be altered to accommodate the Robotrol RMB-731 analog I/O board.

The all "glass cockpit" concept of this project is still centered around the usage of an inexpensive graphics controller and an RGB color monitor. The 186/78 SBC controller board is the direct interface to the Prinston Graphics SR12-P color monitor. The system still utilizes the Intel supplied VDI720 software package. This has proven to be inadaquate for real-time displays because of software overhead. During the past academic year the graphics monitor has been utilized for the display of non real-time data. The students graph the results of a simulation run by displaying normalized curves of appropriate data in color. At present hardcopy of these displays can not be obtained.

The simulation system is centered around Intel's 310 development system. It will be proposed in the future to switch to an IBM PC/AT for all program development. This will make the 310 system the target system for simulation runs. In addition the students can develop software at a number of sites.

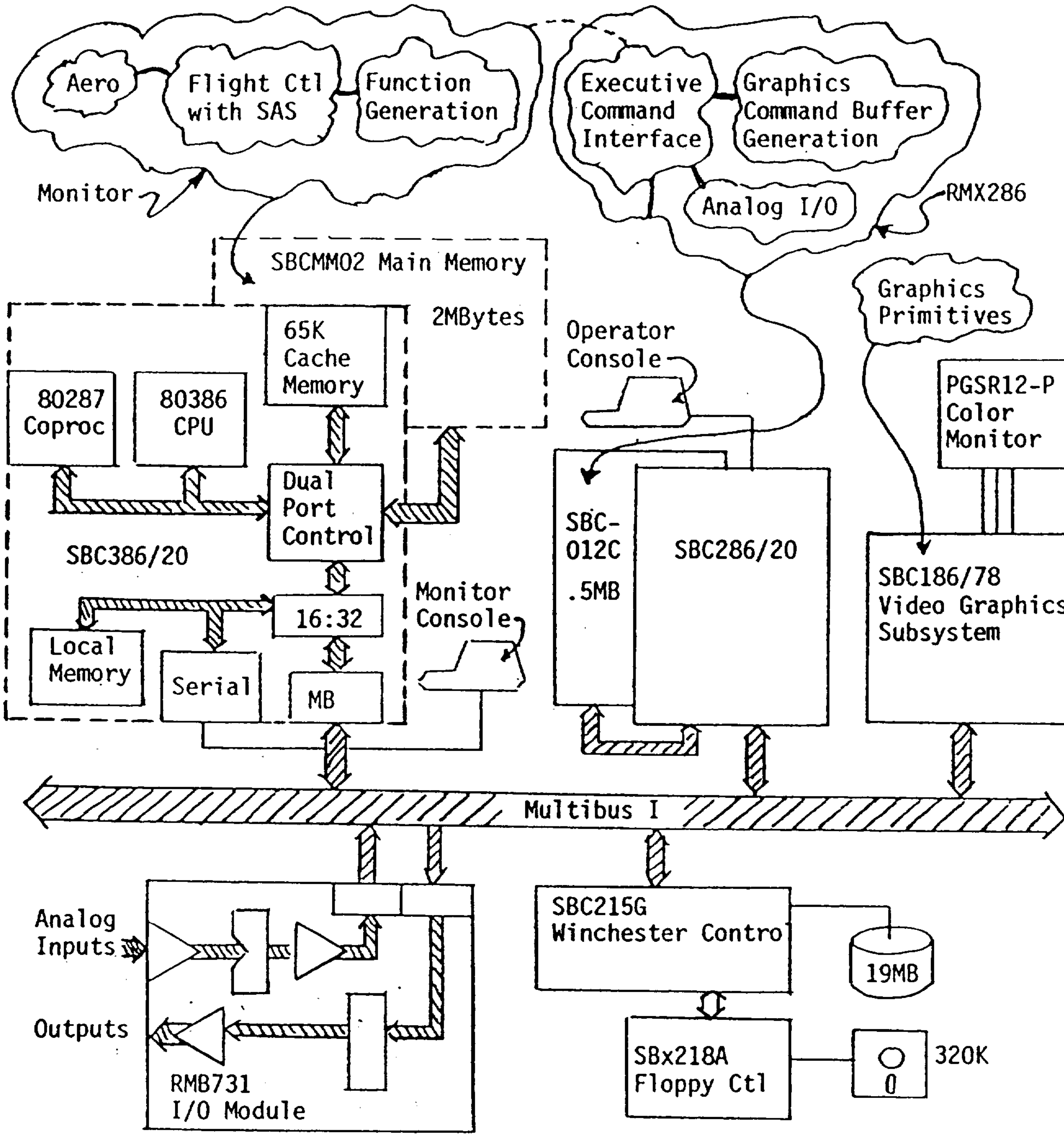

Aero
Flight Ctl with SAS
Function Generation
Executive Command Interface
Graphics Command Buffer Generation
Analog I/O
Monitor
RMX286
SBCMM02 Main Memory
2MBytes
65K Cache Memory
80287 Coproc
80386 CPU
Dual Port Control
SBC386/20
16:32
Local Memory
Serial
MB
Monitor Console
Operator Console
Graphics Primitives
PGSR12-P Color Monitor
SBC-012C .5MB
SBC286/20
SBC186/78 Video Graphics Subsystem
Multibus I
Analog Inputs
Outputs
RMB731 I/O Module
SBC215G Winchester Contro
19MB
SBx218A Floppy Ctl
320K

Figure 1.

CURRENT STATUS

The Intel Flight Simulator System is well suited for the educational environment because of the cost of the system and because it is a modular system. It can be viewed by the students as a complete flight simulator or as an educational tool designed to introduce senior aero students to the world of flight simulation. However the complexity of a multi-processing system without well established graphics has proven to be a disadvantage when the primary goal is modeling and the gathering of data.

For the past academic year the emphasis has been to develop the necessary software modules required to create a "student friendly" environment on the Intel 310 system. It was felt that student concentration should focus on aero modeling, input/output scaling, reduction of data for analysis, sample time, and frame time. Past experience has demonstrated that too much time can be spent introducing the system architecture, the programming environment, and the synchronization problems associated with a parallel processing system. The goal has been to minimize this overhead as it pertains to student involvement. Students concentrate on converting a control or simple simulation model into an equivalent set of equations. They create their own data bases and write their own integration algorithms. These program modules are linked and located for proper execution on the 386/22 processor. All software necessary to transfer their code the the 386 processor has already been developed. In addition the 386 processor supports a custom monitor designed to aid in the execution of the simulation.

To achieve the desired environment over 30 software procedures have been developed, linked and installed on the Intel 310 System during the past academic year. The students invoke the simulation software and follow the menu driven insturctions. The menu insturctions allow the student to perform the following operations:

1. Select and initialize input variables for a given run.

2. Select the input waveforms and limits. At present these include steps, ramps, and doublets. The inputs are software generated as the A/D convertor board can not be installed due to memory constraints.

3. Download the simulation model to the 386/22 SBC for execution. After downloading the simulation model the initial data base is loaded by the 286/10 processor via shared memory. Startup, execution, and simulation run time are all controlled by the 286/10 processor via the command/executive menu.

4. The students can select the amount of data to be collected for display and can direct the data to the 310 system operator console, the printer, or the color graphics display. At present all data directed to the console or the printer is in "character" form only. Hardcopy graphics is not available at this time.

Figure 2 illustrates a simple block diagram of the system as viewed by the students. All input data, updated at a programmed frame rate, is loaded into a common buffer in shared memory. The 386/22 processor reads this data by sampling a "data$flag$in" flag in shared memory. If the flag is "true" the next computation cycle begins. The output results are stored in shared memory by the 386/22 processor and the "data$flag$in" flag is set "false". It is the responsibility of the Intel 286/10 processor to analyze this output data, format it for the proper display, and store the output data in a buffer located in the local memory of the 286/10 processor. The amount of data collected is controlled by the initialization memu and depends upon the selected frame time and the overall run time of the simulation. All code to control the color graphics display resides within the executive module on the 286/10 processor.

Figure 3 illustrates the basic flow control for the simulation model executing on the 386/22 SBC. While this flow control model is somewhat general purpose it is tailored to control elements of the experiment illustrated in Appendix 1. If a different simualtion experiment is to be run on the 386/22 processor it would be the responsibility of the students to alter the flow control of Figure 3 to meet the requirements of the simulation.

The experiment illustrated in Appendix 1 is a simple Pitch Attitude Hold System. The students are required to translate a block diagram of the system into a set of state variable equations. They then test the validity of the equations using MATLAB. After a correlation is obtained with the expected results the students program the equations using the high level language PLM86. They then prepare the equations, integrated with the necessary flow control illustrated in Figure 3, for downloading into the Intel 386/22 processor board. The downloading process is controlled by custom software residing on both the 286/10 processor and the 386/22 processor. The PLM86 program for the Pitch Attitude Hold System is also illustrated in Appendix 1. Results obtained from this experiment were very encouraging, however the amount of effort put forth by the students exceeded that of a normal one or two week experiment.

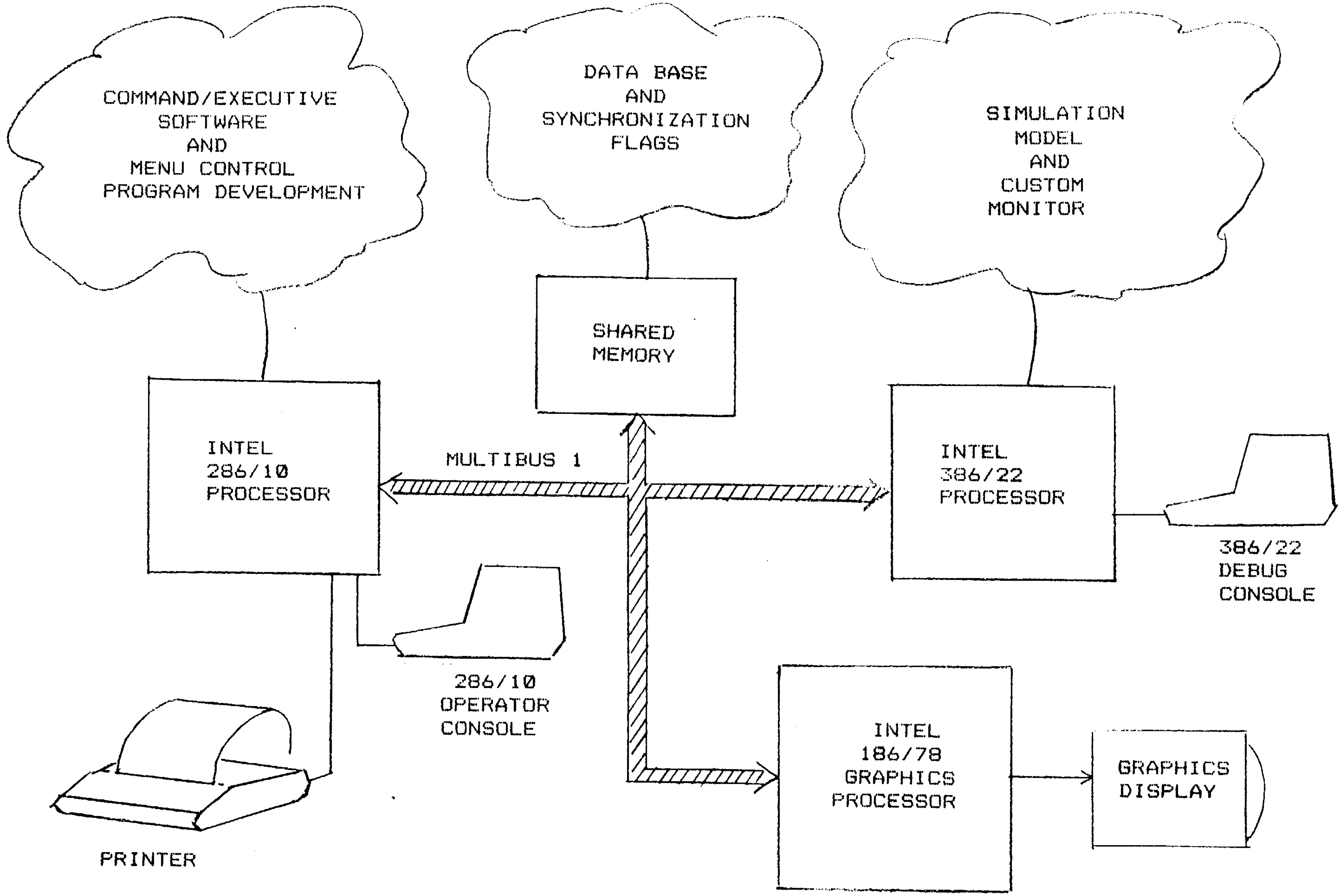

COMMAND/EXECUTIVE
SOFTWARE
AND
MENU CONTROL
PROGRAM DEVELOPMENT
DATA BASE
AND
SYNCHRONIZATION
FLAGS
SIMULATION
MODEL
AND
CUSTOM
MONITOR
SHARED
MEMORY
INTEL
286/10
PROCESSOR
MULTIBUS 1
INTEL
386/22
PROCESSOR
386/22
DEBUG
CONSOLE
286/10
OPERATOR
CONSOLE
INTEL
186/78
GRAPHICS
PROCESSOR
GRAPHICS
DISPLAY
PRINTER

FIGURE 2

Incorporation of the above experiment into a multi-processor system demands a user-friendly environment. For this reason the integration of the above experiment into the aero engineering curriculum required the use of a command/executive menu driven program consisting of over 30 software modules linked together and run as the primary task on the 286/10 processor. The main module program and an explantion of its primary functions is illustrated in Appendix 2. These modules controlled all data entry, console displays, printer output, and the formating of results for output to the VDI720 graphics package. Results were displayed in color on the Prinston Graphics PGSR12-P color monitor. The displays could not be run in real-time because of the software overhead associated with the VDI720 graphics package.

To better understand the limitations associated the the VKI720 graphics package the following reviews the basic structure of VDI and summerizes its performance.

Intel provided the iVDI720 graphics package in ROM to handle graphics routines such as graphics initialization, line draw, text display, circles, etc. Unfortunately, the commands to the controller are difficult to understand and setup. This is mostly due to poor documentation on the part of Intel. Fortunately, Intel provided sample procedural binding to the iVDI720 and it is these procedural bindings that are used to access the iVDI commands.

The graphics controller is attached to the Multibus system as a logical device :VDI:. It is through this logical device name that ROM software can be accessed on the controller. The iVDI720 manual is vague on how to actually send the commands to the ROM. This is where the language binding procedures come in handy. The VDI language binding provides the procedures that send specific commands to the VDI device. The procedures send parameters in the format required by the VDI device.

To use the language binding, the graphics must be initialized by the procedure INIT$GRAPHICS(backgroundcolor). After initialization all other language binding procedures can be called into action. For the experiment in Appendix 1 lines were drawn using LINE(x1,y1,x2,y2). Text was displayed using TEXT(x,y,flag,count,pointer). Of course the appropriate setup needs to be done before calling these procedures. The above procedures are found in the file, VDLANG.EXT. It is well worth while to print out this file. While the file contains absolutely no comments, it does provide the user with a list of commands and required parameters.

SYNCHRONIZATION MODEL

FOR 386/22 ⟷ 286/10

COMMUNICATION

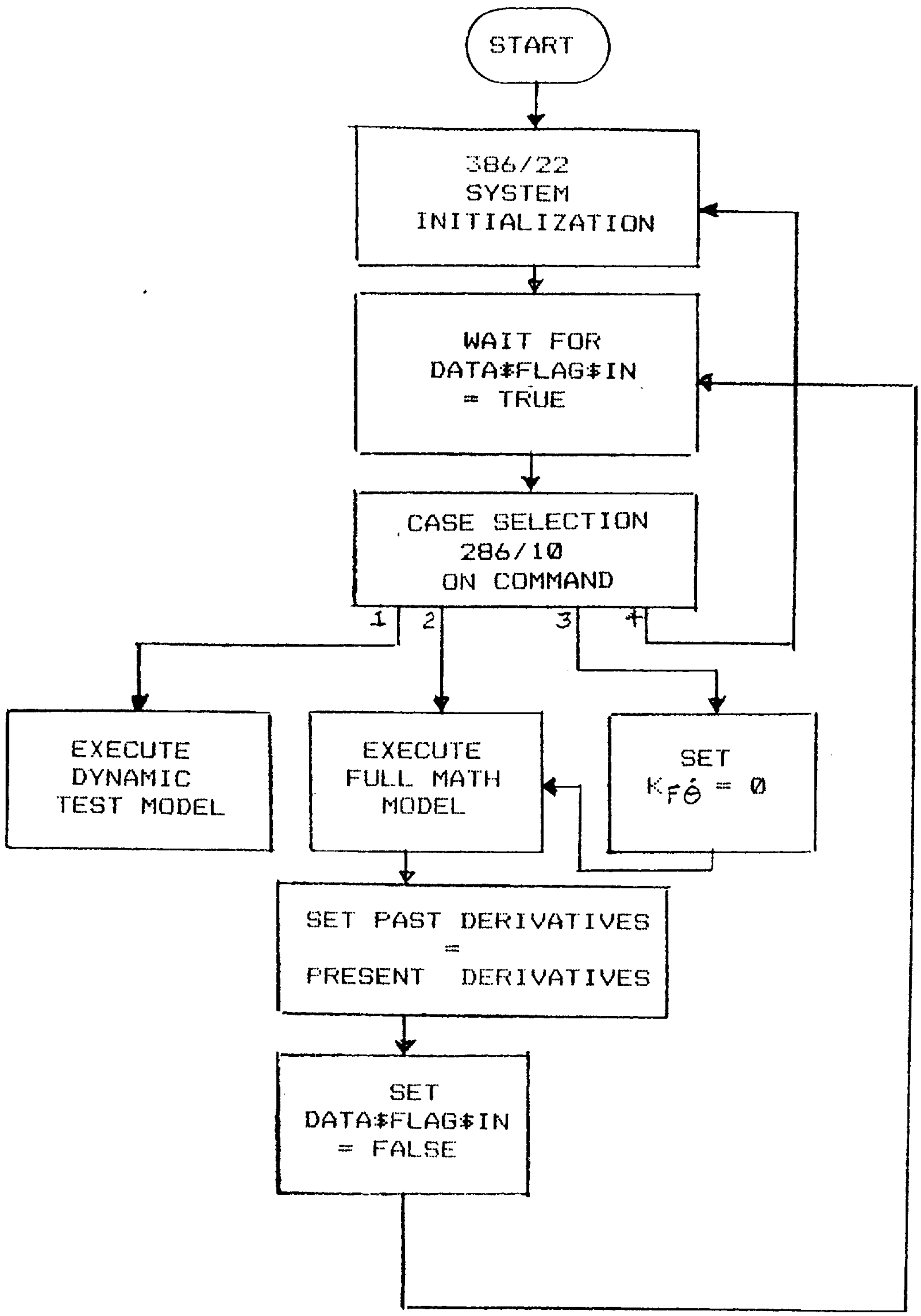


FIGURE 3

Overall the performance of the VDI package is slow. Its performance is on par with graphics on an 8-bit IBM-PC class machine. There are no figures available which allow for a numerical value on the performance. But from the empirical results obtained over several experiments, both real-time and non-real-time, it is safe to say that the VDI package will not allow real-time output of a high speed process.

The only solution for this is to perform the graphics by direct access to the hardware. In general, this is not the purpose of the graphics module when utilized by aero engineering students. However, it is a good problem for a computer science major.

DRAWBACKS AND UPGRADES FOR THE INTEL SYSTEM

Over the past four years the Intel 286/10 based system has undergone considerable change. Most of these changes have involved adding additional hardware and software. In the beginning it was hoped that the system would provide an economical base for real-time flight simulation. Experience has demonstrated that the computing power of the 286/10 coupled to the 386/22 processor is sufficient to support a medium sized simulation that operates it real-time. However, the system will not support real-time insturment displays or any form of an out-the-window display. This is a disappointment considering that PC class machines support flight simulation models adequately as it pertains to the graphics. The models for these simulations may be weak but the displays do operate in pseudo real-time. It must be stated that the system is well suited to static displays like the one's generated for the experiment in Appendix 1. It is unfortunate that hard copy of the displays is not available.

It is obvious that the major problem of the Intel system is the graphics coupled with system configuration limitations. The following suggested solutions would enhance the system a great deal.

1. Increase the 286/10 memory to 1 megabyte. The existing .5 megabytes is inadequate because of limited straping options. I/O can only be performed via the keyboard.

2. Change the operating system to RMX286 and run the 286/10 processor in protected mode. We have RMX286 but it can not be installed unless the memory is incr- eased to at least .7 megabytes. Running in this mode will free up the strapping options and allow for real I/O. The disadvantage is the reconfiguring of all existing software to operate in protected mode.

3. Either rewrite all the graphics software or upgrade the graphics processor. Rewriting the graphics software is a labor intensive job best performed by computer science majors. Upgrading the graphics processor is a cost item coupled with the generation of new software. Either solution is not very attractive at this point as will be explained later.

4. Run the 386/22 processor board in protected mode. This will free up an additional 1 megabyte of memory. Running in protected mode the 386/22 processor can make use of its full 32-bit capability. This would increase its computing power by a factor of 3 or more when running math intensive programs that require a great deal of floating point arithmetic. To do this requires purchasing RMX386 and making a major configuration change to the entire system. This would be both costly and require a great deal of man-hours.

All in all the above solutions still do not create the type of system suitable to aero engineering majors who have limited computing experience at a system level. The multi-processing environment overshadows the main objective of introducing basic problems associated with flight simulation. This can be overcome if aero engineering majors were required to take a few more courses in computer science.

A better solution is to make the system so "canned" that the student need not know any aspect of the problems associated with a multi-processor sytem. To a large extent this has been the main objective of this project and has been successful for executing experiments such as the one outlined in Appendix 1. However, it must noted that the students participating in these experiments were not aero engineering majors but electronic engineering majors. While the electronic majors did not fully understand the aero aspects of the experiments they were fully capable of generating the required support software to make the system apper user-friendly even to a novice computer user. For this reason the sytem is now fully capable of supporting static type experiments, minus the desired hard copy output.

While the above upgrades would provide for fullup real-time flight simulation experiments this could not be achieved without considerable cost ie., $5,000, and many man hours of software development. For this reason an alternate solution is proposed.

AN ALTERNATE SOLUTION AND CONCLUSIONS

The rapid changes in computer technology over the past four years have made systems like the Intel 310 obsolete. At best the 386/22 processor can be considered a 3 to 4 Mips machine when running in protected mode. Even the Intel 486 processor can only be considered an 8 Mip machine. With the advent of RISC technology coupled with new high speed graphics processors the modern "work station" is the way of the future. These work stations, varying in computer power from 10 to 30 Mips, provide a solution for introducing many aspects of flight simulation in the educational environment. Their cost continues to fall. It is now possible to purchase a 27 Mips machine for under $10,000. In addition there are several manufacturers,such as, Sun/Sparc, IBM/6000, DEC/3100, HP/Appollo,NeXT,DG/AViiON, etc. Not all of these work stations employ RISC technology but they all seem to be in the same class. Most come with 8 megabytes of main memory as standard and most suport LAN technology to the fullest. Several of these workstations have DOS emulation as well as UNIX.

One of the major advantages of these machines, when viewed by an aero engineering major, is that the student does not have to have a complete understanding of the system-level hardware or software. They do require a working knowledge of UNIX but this is basic to most major curriculums. At the junior/senior level the students already have a working knowledge of UNIX.

With this idea in mind the system illustrated in Figure 4 is an example of what can be put together for under $20,000. This system would support any medium sized simulation, provide for all instrument display, give a good out-the-window display, and even support avionics displays. The system could operate in real-time, for both computations and graphics. The advantage to such a system is that the student can concentrate on the aero problem and put the system configuration problems in the background. In addition, the system is tailored to interface to a larger network providing a much bigger data base and the opportunity for many students to simultaneously work on one problem or one experiment.

Such a system is already being incorporated into the Electronic Engineering Department. It consists of 8 DEC/3100 work stations with DISC SERVERS. The Flight Simulation Laboratory at Cal Poly is now considering the purchase of two more work stations, either DEC/3100 or IBM/6000 class machines. These machines would be on their own network for high speed communications but would have

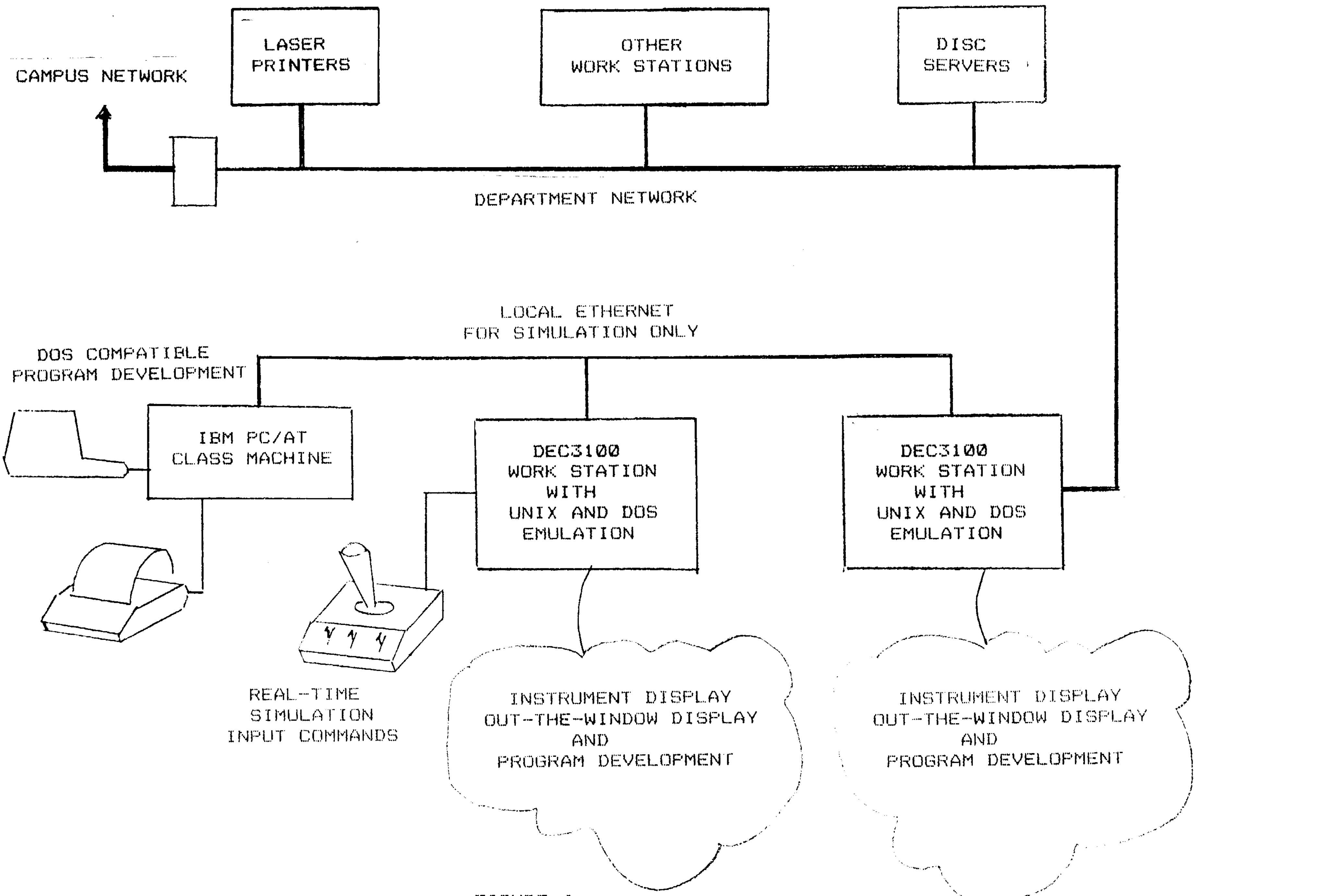

CAMPUS NETWORK
LASER PRINTERS
OTHER WORK STATIONS
DISC SERVERS
DEPARTMENT NETWORK
LOCAL ETHERNET FOR SIMULATION ONLY
DOS COMPATIBLE PROGRAM DEVELOPMENT
IBM PC/AT CLASS MACHINE
DEC3100 WORK STATION WITH UNIX AND DOS EMULATION
DEC3100 WORK STATION WITH UNIX AND DOS EMULATION
REAL-TIME SIMULATION INPUT COMMANDS
INSTRUMENT DISPLAY OUT-THE-WINDOW DISPLAY AND PROGRAM DEVELOPMENT
INSTRUMENT DISPLAY OUT-THE-WINDOW DISPLAY AND PROGRAM DEVELOPMENT

FIGURE 4

direct access to the department network for file transfer operations. Because the department network is connected campus wide students in aero engineering would have access to the two work stations reserved for flight simulation.

It is hoped that this system will create an environment where flight simulation experiments can become a permanent part of the aero engineering curriculum.

It should be noted that the Intel 310 system can still play an important part for senior project studies and master thesis work. This is particularly true for electronic engineering majors and computer science majors.

APPENDIX 1

PITCH ATTITUDE HOLD SYSTEM

EXPERIMENT

EL 520 PROJECT

PITCH ATTITUDE HOLD SYSTEM MODEL AND SIMULATION PROGRAM

PURPOSE

1. Gain experience in the formulation of continuous dynamic system models defined in block diagram form.

2. Gain experience in the programming and checkout of a simulation model running on two microprocessors that communicate with each other over Multibus I. In addition, gain experience in the formulation of math-intensive programs that utilize NDP coprocessors.

PROCEDURE

1. From the given block diagram formulate the equivalent system of equations for the system simulation model.

2. Prepare a PLM-86 program that implements the simulation. The program shall consist of 5 parts: 1. The main module; 2. A procedure to simulate the input to the model; 3. The model; 4. A procedure to output the results to a printer in numerical form and output the results to a CRT in graphical form; 5. A procedure to handle communication between the 286/10 processor and the 386/22 processor.

3. NOTE: The simulation model should run on the 386 processor. All results are to be passed to the 286 processor for scaling and output.

4. Refer to the block diagram. With the elevator servo locked at zero position run the short period response of the airframe to the $+/-10^{o}$ elevator dublet and verify your pitch rate response with the dynamic check data.

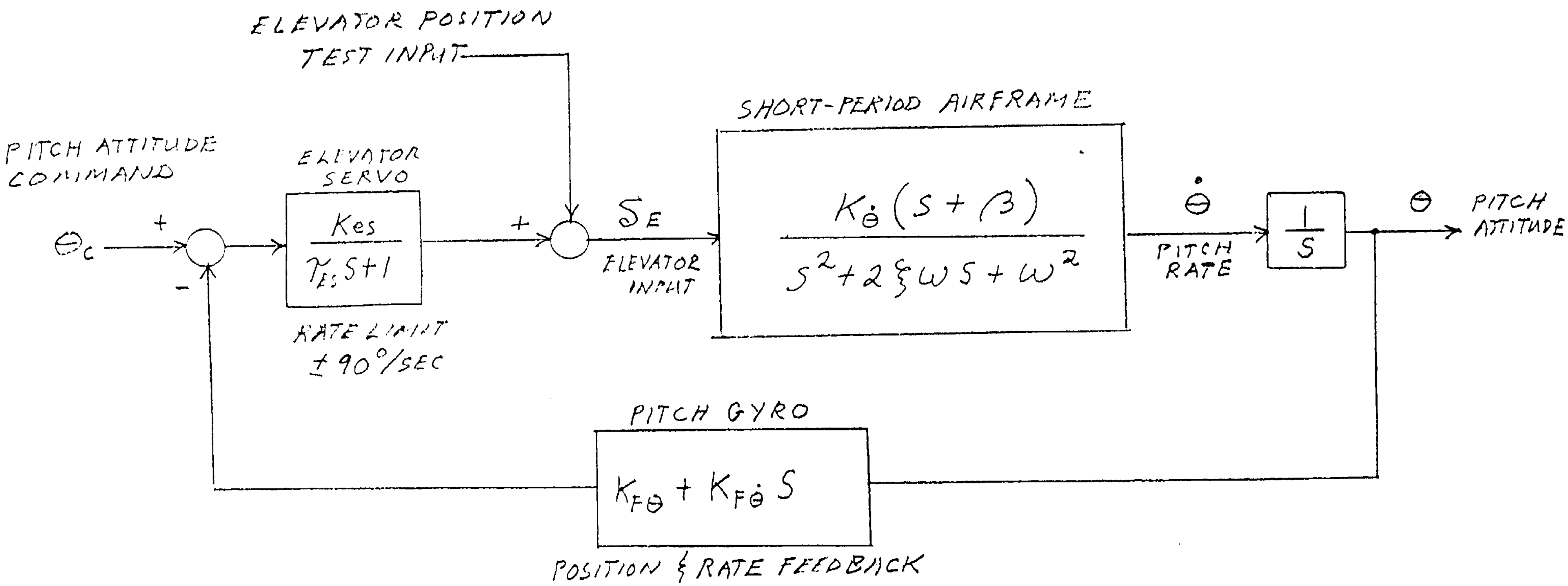
5. Run the complete simulated pitch attitude hold system response to a $+5^{o}$ step command θ_c starting from zero initial conditions. Plot the following variables versus time: θ_c, δ_E, $\dot{\theta}$, θ

6. Run the step response with $K_{F\dot{\theta}} = 0$ simulating the loss of pitch rate feedback.

NOTE: The following time constraints apply: Step size (DT) = .001 sec
Sample time = .01 sec
Run time = 10 sec

7. Prepare one report that presents your methods, results and interpretation of the system performance.

PITCH ATTITUDE HOLD SYSTEM



$K_{es} = +.1$

(Kes IS POSITIVE IF TRAILING EDGE IS DOWN ON ELEVATOR)

$\tau_{ES} = .03$ SEC

$K_{\dot\Theta} = .0322$

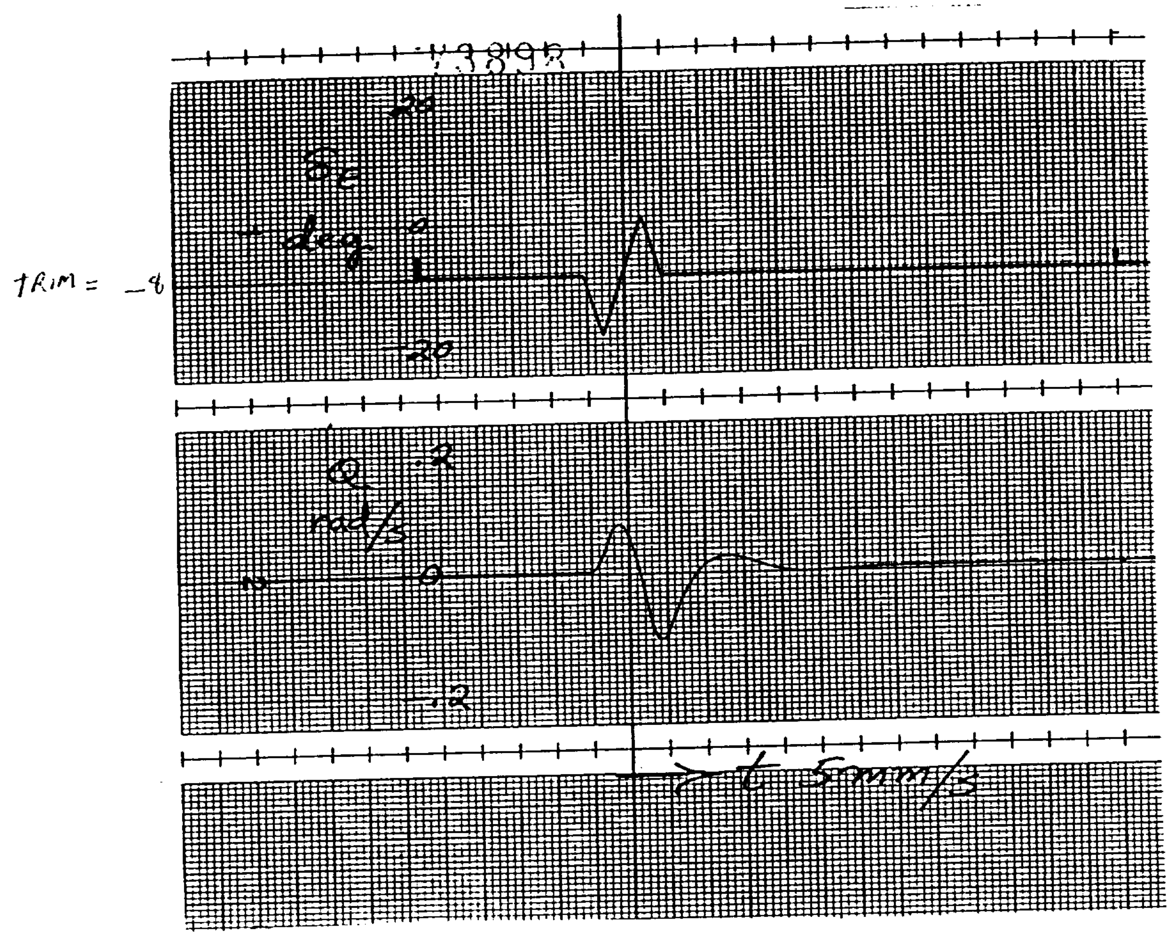
$\beta = .53$

$\omega = 1.63$ RADS/SEC

$\xi = .5$ (DAMPING COEFFICIENT)

$K_{F\Theta} = 2.0$ (POSITION FEEDBACK)

$K_{F\dot\Theta} = 1.0$ (RATE FEEDBACK)



T4B DYNAMIC CHECK

Elevator doublet (10 deg/2 sec)

Approach trim flight condition:

H 500 ft

KEAS 100 Knots

Flaps 35°

Gear down

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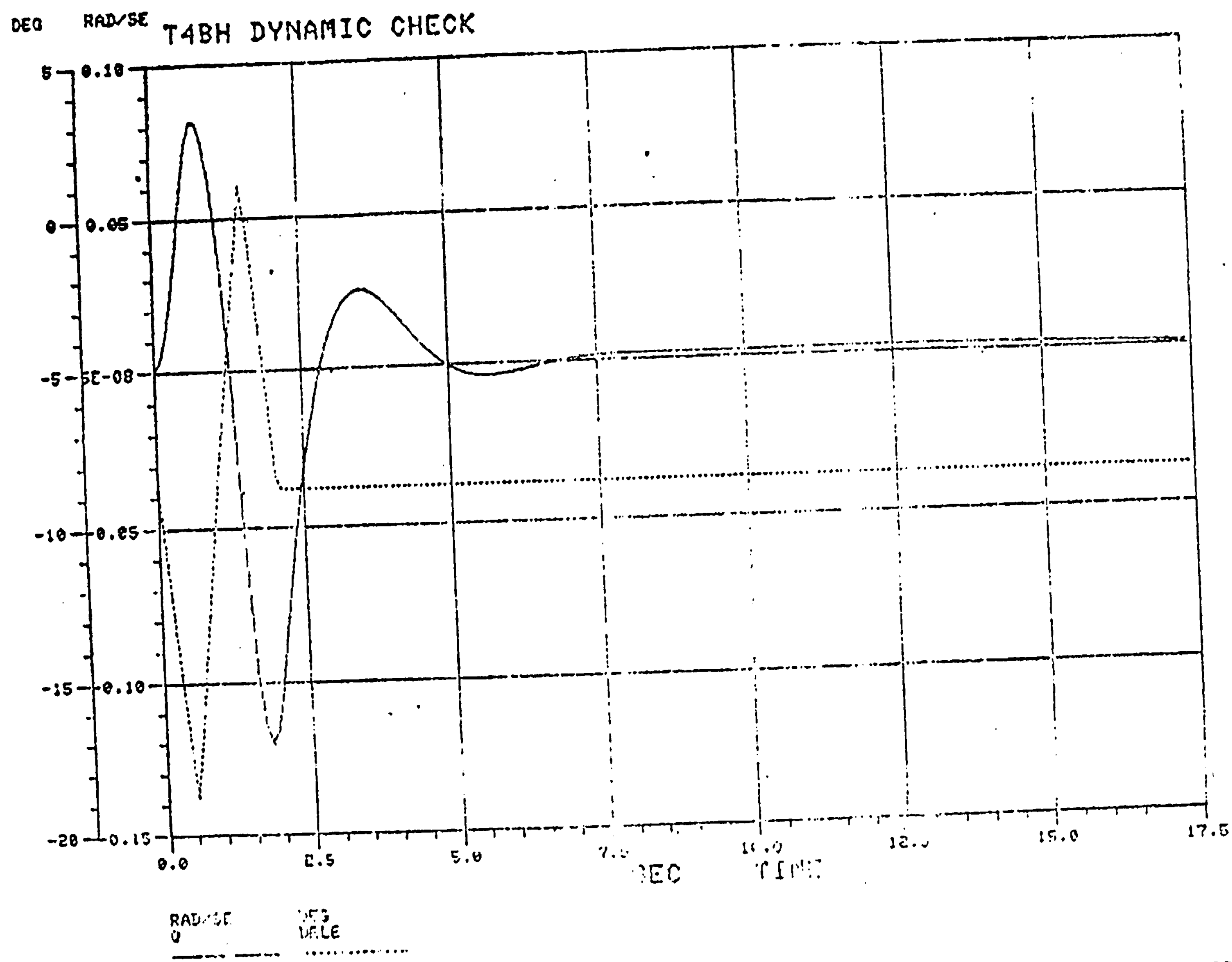
RUN 0



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```
iRMX 86 PL/M-86 V2.3 COMPILATION OF MODULE MATHMODEL
OBJECT MODULE PLACED IN MATH.OBJ
COMPILER INVOKED BY:  :LANG:plm86 MATH.PLM


                $SYMBOLS
                $DEBUG
                $LARGE
                $RAM

    1           MATH$MODEL: DO;

                /*  COMMON BLOCK DECLARE STATEMENT FOR VALUE PASSING  */

    2   1       DECLARE
                        STUFF STRUCTURE ((COMMAND, DATA$FLAG$IN, DUMMY1, DUMMY2) B
YTE,
                        (DATA$IN, DELTA$E, THETA$PRIME, THETA, TIME$STEP) REAL)
                        AT (0E0000H);

    3   1       DECLARE
                        (K$ES, TAU$ES, K$THETA$PRIME, BETA, OMEGA, ZETA, K$F$THETA
,
                        K$F$THETA$PRIME, F, DELTA$E$PRIME$PAST, Y$PRIME$PAST,
                        Y$PAST, THETA$PRIME$PAST, Y, DELTA$E$PRIME, Y$PRIME,
                        Z, Z$PRIME, Z$PAST, Z$PRIME$PAST, X) REAL
                        INITIAL (10.0, 0.03, 0.0322, 0.53, 1.63, 0.5, 1.0, 2.0);


                /*  PROCEDURE DEFINITIONS  */

    4   1       DYNAMIC$TEST:PROCEDURE;
                /*  TEST INPUT.  ELEVATOR SERVO LOCKED AT ZERO DEGREES.
                    DATA$IN IS REALLY A SUPPLIED VALUE OF DELTA$E  */

    5   2           STUFF.DELTA$E = -1.0*STUFF.DATA$IN;

    6   2           Z$PRIME = STUFF.DELTA$E - 2.0*ZETA*OMEGA*Z - OMEGA*OMEGA*X;

    7   2           Z = Z + (STUFF.TIME$STEP/2.0)*(3.0*Z$PRIME - Z$PRIME$PAST);

    8   2           X = X + (STUFF.TIME$STEP/2.0)*(3.0*Z - Z$PAST);

    9   2           STUFF.THETA$PRIME = K$THETA$PRIME*(Z + BETA*X);

   10   2       END DYNAMIC$TEST;

   11   1       FULL$MODEL:PROCEDURE;

                /*  DELTA$E IS IN DEGREES WHILE THETA$PRIME IS IN RADIANS/SECOND.
                    THETA IS TO BE IN DEGREES, THUS THE REQUIRED CONVERSION FACTOR
                    IN THE INTEGRATION AND FEEDBACK FORMULAE  */


   12   2           DELTA$E$PRIME = (K$ES*(STUFF.DATA$IN - F) - STUFF.DELTA$E)/TAU
$ES;

   13   2           IF (DELTA$E$PRIME > 90.0) THEN
```

```
  15    2                ELSE IF (DELTA$E$PRIME < -90.0) THEN
  16    2                    DELTA$E$PRIME = -90.0;

  17    2          STUFF.DELTA$E = STUFF.DELTA$E + (STUFF.TIME$STEP/2.0)*
                                  (3.0*DELTA$E$PRIME - DELTA$E$PRIME$PAST);

  18    2          Y$PRIME = K$THETA$PRIME*(DELTA$E$PRIME + BETA*STUFF.DELTA$E)
                            - 2.0*ZETA*OMEGA*Y - OMEGA*OMEGA*STUFF.THETA$PRIME;

  19    2          Y = Y + (STUFF.TIME$STEP/2.0)*(3.0*Y$PRIME - Y$PRIME$PAST);

  20    2          STUFF.THETA$PRIME = STUFF.THETA$PRIME + (STUFF.TIME$STEP/2.0)*
                                      (3.0*Y - Y$PAST);

  21    2          STUFF.THETA = STUFF.THETA +(57.29577951)*(STUFF.TIME$STEP/2.0)
*
                                 (3.0*STUFF.THETA$PRIME - THETA$PRIME$PAST);

  22    2          F = K$F$THETA*STUFF.THETA +
                       (57.29577951)*K$F$THETA$PRIME*STUFF.THETA$PRIME;

  23    2      END FULL$MODEL;


  24    1          CALL INIT$REAL$MATH$UNIT;        /*  INITIALIZE MATH CHIP   */

  25    1          RESTART:         /*  INITIALIZE SYSTEM INITIAL CONDITIONS   */
                   STUFF.DATA$FLAG$IN = 0;
  26    1          STUFF.DELTA$E = 0.0;
  27    1          STUFF.THETA$PRIME = 0.0;
  28    1          STUFF.THETA = 0.0;
  29    1          F = 0.0;
  30    1          DELTA$E$PRIME$PAST = 0.0;
  31    1          Y$PRIME$PAST = 0.0;
  32    1          Y$PAST = 0.0;
  33    1          THETA$PRIME$PAST = 0.0;
  34    1          Y = 0.0;
  35    1          DELTA$E$PRIME = 0.0;
  36    1          Y$PRIME = 0.0;
  37    1          Z = 0.0;
  38    1          Z$PRIME = 0.0;
  39    1          Z$PAST = 0.0;
  40    1          Z$PRIME$PAST = 0.0;
  41    1          X = 0.0;
  42    1          K$F$THETA$PRIME = 2.0;

  43    1          LOOP:                               /* MAIN LOOP */
                   DO WHILE (STUFF.DATA$FLAG$IN = 0);
  44    2          END;

  45    1          DO CASE STUFF.COMMAND;
  46    2              ;

  47    2              CALL DYNAMIC$TEST;

  48    2              CALL FULL$MODEL;

  49    2              DO;
```

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```
 50    3                    K$F$THETA$PRIME = 0.0;
 51    3                    CALL FULL$MODEL;
 52    3                END;

 53    2                GOTO RESTART;

 54    2            END;

 55    1            DELTA$E$PRIME$PAST = DELTA$E$PRIME;
 56    1            Y$PRIME$PAST = Y$PRIME;
 57    1            Y$PAST = Y;
 58    1            THETA$PRIME$PAST = STUFF.THETA$PRIME;
 59    1            Z$PRIME$PAST = Z$PRIME;
 60    1            Z$PAST = Z;

 61    1            STUFF.DATA$FLAG$IN = 0;       /*  RESET DATA FLAG  */
 62    1            GOTO LOOP;                    /*  WAIT FOR NEXT DATA POINT  */

 63    1        END MATH$MODEL;
```

SYMBOL LISTING

```
 DEFN  ADDR    SIZE  NAME, ATTRIBUTES, AND REFERENCES
 ----  ------  ----  --------------------------------


       0000H     4   BETA . . . . . . . .     REAL INITIAL
       0038H     4   DELTAEPRIME. . . . .     REAL INITIAL
       0024H     4   DELTAEPRIMEPAST. . .     REAL INITIAL
       0123H   200   DYNAMICTEST. . . . .     PROCEDURE STACK=0002H
       0020H     4   F. . . . . . . . . .     REAL INITIAL
       01EBH   397   FULLMODEL. . . . . .     PROCEDURE STACK=0004H
       0000H     4   KES. . . . . . . . .     REAL INITIAL
       0018H     4   KFTHETA. . . . . . .     REAL INITIAL
       001CH     4   KFTHETAPRIME . . . .     REAL INITIAL
       0008H     4   KTHETAPRIME. . . . .     REAL INITIAL
       0080H         LOOP . . . . . . . .     LABEL
       0002H   289   MATHMODEL. . . . . .     PROCEDURE STACK=0006H
       0010H     4   OMEGA. . . . . . . .     REAL INITIAL
       000AH         RESTART. . . . . . .     LABEL
     EH0000H    24   STUFF. . . . . . . .     STRUCTURE AT ABSOLUTE
       0000H     1       COMMAND. . . . .     BYTE
       0001H     1       DATAFLAGIN . . .     BYTE
       0002H     1       DUMMY1 . . . . .     BYTE
       0003H     1       DUMMY2 . . . . .     BYTE
       0004H     4       DATAIN . . . . .     REAL
       0008H     4       DELTAE . . . . .     REAL
       000CH     4       THETAPRIME . . .     REAL
       0010H     4       THETA. . . . . .     REAL
       0014H     4       TIMESTEP . . . .     REAL
       0004H     4   TAUES. . . . . . . .     REAL INITIAL
       0030H     4   THETAPRIMEPAST . . .     REAL INITIAL
       0050H     4   X. . . . . . . . . .     REAL INITIAL
       0034H     4   Y. . . . . . . . . .     REAL INITIAL
       002CH     4   YPAST. . . . . . . .     REAL INITIAL
       003CH     4   YPRIME . . . . . . .     REAL INITIAL
       0028H     4   YPRIMEPAST . . . . .     REAL INITIAL
       0040H     4   Z. . . . . . . . . .     REAL INITIAL
       0014H     4   ZETA . . . . . . . .     REAL INITIAL
       0048H     4   ZPAST. . . . . . . .     REAL INITIAL
       0044H     4   ZPRIME . . . . . . .     REAL INITIAL
       004CH     4   ZPRIMEPAST . . . . .     REAL INITIAL
```

```
MODULE INFORMATION:

     CODE AREA SIZE     = 0378H    888D
     CONSTANT AREA SIZE = 001CH     28D
     VARIABLE AREA SIZE = 0054H     84D
     MAXIMUM STACK SIZE = 0006H      6D
     127 LINES READ
     0 PROGRAM WARNINGS
     0 PROGRAM ERRORS

DICTIONARY SUMMARY:

     64KB MEMORY AVAILABLE
```

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SYMBOL LISTING

```
     5KB MEMORY USED    (7%)
     0KB DISK SPACE USED

END OF PL/M-86 COMPILATION
```

```
LINK86  MATH.OBJ,                                &
        /LIB/NDP87/DCON87.LIB,                   &
        /LIB/NDP87/CEL87.LIB,                    &
        /LIB/NDP87/EH87.LIB,                     &
        /LIB/NDP87/8087.LIB                      &
        TO MATH.LNK INITCODE

LOC86   MATH.LNK TO MATH.EXE INITCODE                  &
        ADDRESSES( CLASSES(CODE(0A0000H),              &
                           DATA(0A2000H),              &
                          STACK(0A3000H),              &
                         MEMORY(0A4000H)),             &
           SEGMENTS(LIB_87_INIT(0A5000H),              &
                    LIB_87_PUB(0A6000H),               &
                          ??SEG(0A7000H)))

OH86    MATH.EXE TO MATH.HEX
```

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APPENDIX 2

286/10 COMMAND/EXECUTIVE MENU CONTROLLER

$COMPACT

/***
main module for the pitch attitude hold system simulator

The pitch attitude simulator simulates the PD controller used
to control the pitch attitude for an aircraft. This simulator
consists of two parts, one running on the 80386 board and another
on the 80286 board. The equations and calculations used to
simulate the controller are performed on the 386 board, while the
286 program mainly collects signal simulation data that is output from
the 386 and then displays this data. The communication between the two
boards is through multibus and is flag driven.

The user first loads the simulation module onto the 386 board. He
then executes the main program called main_tst on the 286 system.
The input signal to the controller is a simulated version of the command
signal that would be obtained if it had been input into the computer by
an analog to digital converter. Thus, the user must set a sample time
which is used to construct this simulated command signal and is also used
for simulating the controller. The user may also set the total simulation
time, and the time between display updates. Once the signal and times
have been selected the simulation begins.

The 286 uses timer 2 of the 8254 timer to control when the next sample
of the input signal is to be sent to the 386. For example, if a 1ms
sample time has been selected, then the 8254 is set so that it reaches
terminal count every 1ms. When we detect that it has reached terminal
count, timer_interrupt_routine is called which sets the continue_simulation
flag and sets theta in of the controller to the next value of the input
signal. (This makes it look like we are actually sampling the input signal
every 1ms and then passing it to the 386 simulator). The timer is then
reloaded and will count off another 1ms period. The continue_simulation_flag
tells the 386 that a new value for the input signal is ready to be
processed

Also, at this time we check to see if we should be recording the data
that has been output by the 386 board. This data consists of various
signals from the controller such as theta out, derivative of theta out,
and delta error. This determination is made by looking at the value
for time step size. This entire process is reapeated until we reach the
end of the simulation.

The 386 program will wait until it sees continue_simulation flag set
to true. It then will process the new data that the 286 has given it
and store the new values of the output signals that we are measuring.
It is assumed that the 386 will reset continue_simulation flag after
it has processed the data and will then remain idle until continue
simulation flag becomes high again.

The 386 program must be passed the sample time and the simulation type
from the 386. The simulation type alters the controller model
that will be used in the simulation. A 1 indicates a elevator dublet
will be used and that the elevator servo should be locked a 0 degrees.
A 2 indicates that the full model is to be used, and a 3 indicates
that the full model should be used but the velocity feedback coefficient
should be set to 0. Finally, a 4 indicates that a new simulation run
is about to be started and that the 386 program should reset itself.

All communication between the two programs is done through multibus
starting at address E00000. The names of the variables passed between
the two programs are simulation_type, sample_time, new_theta_in,

```
Once the simulation has been completed, the user can display the
results in either a tabular format (to the screen or printer) or in
a graphical format on the color monitor.  After viewing the variables
he desires, he may quit the simulator or run a new simulation

*****************************************************************************/

main_module:  do;

$include(:sd:user/controls/paul/basetype.plm)
$include(:sd:user/controls/paul/io286.h)
$include(/rmx86/inc/uexit.ext)
$include(:sd:user/controls/paul/add_io.h)
$include(:sd:rmx86/vdi/vdlang.ext)
$include(:sd:user/controls/paul/colors)

/****************************************************************************
    global variables used in this program

        all variables that have been absoluted at E00000 or above
        are used to pass information back and forth between this
        program and the simulator running on the 386 board

        variables          - the number of signals from the 386 that we will be
                             recording in our simulation
        end_simulation     - used to tell the 386 simulator to reset itself
        variable_name      - stores the names of the signals we are recording
                             data for
        simulation         - array used to store all the data from the simulation
        input_signal       - array used to store the simulated input signal to the
                             controller (theta in)
        simulation_type    - the type of simulation we will be running (1 - 3)
                             (described above)
        continue_sim_flg-  tells the 386 that the next value of the input signal
                             is ready to be processed
        simulation_time    - the total time for the simulation in seconds
        sample_time        - the time between each data point in the input signal
        time_step_size     - the time between each update of the display
        lst,con            - used by write_ln to send information to the
                             printer (lst) or console (con)
 ****************************************************************************/

declare
    data_array_size                   literally    '1001',
    signal_array_size                 literally    '10001',

    variables                         literally    '4',

    theta_ref                         literally    '0',
    delta_e                           literally    '1',
    theta_out                         literally    '2',
    deriv_theta_out                   literally    '3',

    end_simulation                    literally    '4',

    variable_name(variables)          string,

    simulation (variables)            structure (dat (data_array_size) real),
    input_signal(signal_array_size)         real,

    simulation_type                   byte at (0E0000H),
    continue_simulation_flag          byte at (0E0001H) initial(0),
```

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```
    new_delta_e                    real at ([illegible]) initial(0.0),
    new_deriv_theta_out            real at (0E000CH) initial(0.0),
    new_theta_out                  real at (0E0010H) initial(0.0),

    simulation_time                real,
    sample_time                    real,
    absolute_sample_time           real at (0E0014H),
    time_step_size                 real,

    /* the following are used to program the counter 2 of the 8254 timer
       to count off the sample time */

    i8254_counter_2_addr           literally    '00D4H',
    i8254_counter_2_byte_high      byte,
    i8254_counter_2_byte_low       byte,
    timer_rate                     real initial (0.000001),

    i8254_control_word_addr        literally    '00D6H',

    done                           byte,
    lst                            word,
    con                            word;


/*#############################################################################
    some general input/output procedures
 #############################################################################*/

/*****************************************************************************
 answer_to_question - this procedure returns either Y or N in response to
                      a question that is contained in output_string

 parameters -
    output_string_ptr - pointer to the string containing the question to
                        be asked
 *****************************************************************************/


answer_to_question:                procedure(output_string_ptr) byte;
    declare
        output_string_ptr          pointer,
        output_string              based output_string_ptr string,
        response                   byte,
        done                       byte,
        input_char                 byte;

    call clear$screen;

    call write_ln(con,@output_string);

    done = false;

    do while (not done);
        do while (not keypressed);
        end;

        input_char = character$in;

        if ((input_char = 'n') or (input_char = 'N')) then
            do;
                done = true;
                response = 'N';
            end;
            else if ((input_char = 'y') or (input_char = 'Y')) then
                do;
```

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```
                  end;
    end;

    call write_ln(con,@(2,'\n'));
    return(response);

end answer_to_question;

/**************************************************************************
 get_real_parameter - this procedure reads in a new value for a real parameter
                      that is used by the program.  It displays the name of
                      the variable and then asks the user for a new value.
                      If he just presses return then the value is left alone.

 parameters -
    output_string_ptr - pointer to the name of the variable to be altered
    real_value_ptr    - pointer to its current value
    default           - true if we are to display the variables default value
                        when we ask the user for its new value
 *************************************************************************/

get_real_parameter:                procedure(output_string_ptr,real_value_ptr,defa
ult);
    declare
        output_string_ptr          pointer,
        real_value_ptr             pointer,
        real_value                 based real_value_ptr real,
        default                    byte,
        realstring                 string;

    call write_ln(con,output_string_ptr);
    if (default = true) then
        do;
            call real_string(real_value,@realstring);
            call write_ln(con,@(0,'[ default = ^'));
            call write_ln(con,@realstring);
            call write_ln(con,@(0,'] : ^'));
        end;

    call readln(true,@realstring);

    if (realstring.len <> 0) then
        call string_to_real(@realstring,real_value_ptr);
 end get_real_parameter;

/**************************************************************************
 get_integer_parameter - this procedure reads in a new value for a intege param
                         that is used by the program.  It displays the name of
                         the variable and then asks the user for a new value.
                         If he just presses return then the value is left
                         alone.

 parameters -
    output_string_ptr - pointer to the name of the variable to be altered
    integer_value_ptr - pointer to its current value
    default           - true if we are to display the variables default value
                        when we ask the user for its new value
 *************************************************************************/

get_integer_parameter:             procedure(output_string_ptr,integer_value_ptr,d
efault);
    declare
        output_string_ptr          pointer,
        integer_value_ptr          pointer,
```

```
        temp_real_value             real,
        integerstring               string;

    call write_ln(con,output_string_ptr);

    if (default = true) then
        do;
            call integer_string(integer_value,@integerstring);
            call write_ln(con,@(0,'[ default = ^'));
            call write_ln(con,@integerstring);
            call write_ln(con,@(0,'] : ^'));
        end;

    call readln(true,@integerstring);

    if (integerstring.len <> 0) then
        do;
            call string_to_real(@integerstring,@temp_real_value);
            integer_value = fix(temp_real_value);
        end;

end get_integer_parameter;

/*#########################################################################
    routines to setup timer 2 of the 8254 to count off the sample
    time before we send the next value of the input signal to the 386
 #########################################################################*/

/*************************************************************************
 load_8254_timer_2 - this procedure reloads the timer 2 of the 8254 with
                     its count
 parameters- none
 *************************************************************************/

load_8254_timer_2:                  procedure;

    output(i8254_counter_2_addr) = i8254_counter_2_byte_high;
    output(i8254_counter_2_addr) = i8254_counter_2_byte_low;

end load_8254_timer_2;

/*************************************************************************
 setup_sample_time - this procedure calculates the values that need to
                     be loaded into the 8254 in order for it to count
                     off the sample time.

 parameters -
    sample_time - the amount of time that the 8254 is supposed to count
                  off before we send the next value of the input to the 386
 *************************************************************************/

set_up_sample_timer:                procedure(sample_time);

    declare
        i8254_mode_control_word  literally    '0B0H',

        timer_count                 integer,
        sample_time                 real;

    timer_count = fix( sample_time / timer_rate);

    i8254_counter_2_byte_high = high(unsign(timer_count));
    i8254_counter_2_byte_low  = low(unsign(timer_count));
```

```
end set_up_sample_timer;

/***********************************************************************
 check_for_interrupt - this procedure checks the status bit of the
                       8254 to see if it has reached terminal count yet
                       It returns true if it has
 ***********************************************************************/

check_for_interrupt:                   procedure byte;
    declare
        i8254_read_back_control_word    literally    'OD8H',
        mask_byte                       literally    '80H',
        status_counter_2                byte;

    output(i8254_control_word_addr) = i8254_read_back_control_word;
    status_counter_2 = input(i8254_counter_2_addr) and mask_byte;

    if (status_counter_2 = mask_byte) then return(true);
       else return(false);

end  check_for_interrupt;

/*#####################################################################
    routine which handles communication between 386 and 286
 #####################################################################*/

/***********************************************************************
 timer_interrupt_routine - this procedure takes the next value of the
                           input signal and gives it to the 386 simulator
                           If we are supposed to store the output signals
                           for this particular sample then it will place
                           the values for delta_e, deriv_theta_out, and
                           theta_out in the simulation data array.
                           It also sets continue simulation flag for the 386
                           and reloads the timer.
 parameters -
    time_index          - the current time in the simulation we are running
    data_storage_index  - pointer to the next available location in the
                          simulation data array.
    store_variables     - set to true if we are supposed to store info from
                          the last sample of the simulation
 ***********************************************************************/

timer_interrupt_routine:               procedure(time_index,data_storage_index,
                                                 store_variables);


    declare
        time_index                     integer,
        data_storage_index             integer,
        store_variables                byte,
        result_string                  string;


    call load_8254_timer_2;

    if (store_variables = true) then
        do;
            simulation(delta_e).dat(data_storage_index) = new_delta_e;
            simulation(theta_out).dat(data_storage_index) = new_theta_out;
            simulation(deriv_theta_out).dat(data_storage_index) = new_deriv_thet
a_out;
            simulation(theta_ref).dat(data_storage_index) = input_signal(time_in
```

```
    end;

    new_theta_ref = input_signal(time_index);

    continue_simulation_flag = true;
end timer_interrupt_routine;



/*#########################################################################
    routines which build the input signal for the controller
##########################################################################*/

/*************************************************************************
 simulate_doublet_input_to_model - builds a +/- 10 degree 2 second elevator
                                   doublet input to the airframe


 parameters-
    simulation_time - the total time of the simulation
    sample_time     - the time between input signal samples to the controller
**************************************************************************/

simulate_doublet_input_to_model: procedure (simulation_time, sample_time);
    declare
        index                       integer,

        simulation_time             real,
        sample_time                 real,

        (time_1,time_2,time_3)      real;


    time_1 = (0.5/sample_time);
    time_2 = (1.5/sample_time);
    time_3 = (2.0/sample_time);

    do index = 0 to fix(simulation_time/sample_time);
        input_signal(index) = 0.0;
    end;

    do index = 1 to fix(time_1);
        input_signal(index) = (-10.001 * float(index)/time_1);
    end;

    do index = fix(time_1) to fix(time_2);
        input_signal(index) = (20.00 * (float(index) - time_1)/
                                 (time_2 - time_1)) + -10.001;

    end;

    do index = fix(time_2) to fix(time_3);
        input_signal(index) = (-10.00 * (float(index) - time_2)/
                                 (time_3 - time_2)) + 10.001;

    end;

end simulate_doublet_input_to_model;


/*************************************************************************
 simulate_step_input_to_model - builds a 5 degree step input to the
                                controller

 parameters-
    simulation_time - total simulation time
    sample_time     - time between input signal samples to the controller
    time_step_size  - time between display updates of the simulation data
**************************************************************************/
```

```
simulate_step_input_to_model:         procedure(simulation_time,sample_time,
                                                time_step_size);

    declare
        index                         integer,

        simulation_time               real,
        sample_time                   real,
        time_step_size                real;


    do index = 0 to (2 * fix(time_step_size/sample_time));
        input_signal(index) = 0.0;
    end;

    do index = (2 * fix(time_step_size/sample_time)) to fix(simulation_time/samp
le_time);
        input_signal(index) = 5.00;
    end;

end simulate_step_input_to_model;


/****************************************************************************
 get_time_constraints - this procedure asks the user for the simulation
                        time, sample time, and time step size for the
                        current simulation run.


 parameters-
    ptr_sample_time     - pointer to the value for the sample time
    ptr_time_step_size  - pointer to the value for the time step size
    ptr_simulation_time- pointer to the value for the simulation time

 ****************************************************************************/

get_time_constraints:                 procedure(ptr_sample_time,ptr_time_step_size,
                                                ptr_simulation_time);


    declare
        ptr_sample_time               pointer,
        ptr_time_step_size            pointer,
        ptr_simulation_time           pointer;

    call clear$screen;

    simulation_time = 10.00;
    sample_time = 0.001;
    time_step_size = 0.010;

    call get_real_parameter(@(0,'input sample time ~'),ptr_sample_time,true);

    call get_real_parameter(@(0,'input time step size ~'),ptr_time_step_size,tru
e);

    call get_real_parameter(@(0,'input simulation time ~'),ptr_simulation_time,t
rue);

end get_time_constraints;

/****************************************************************************
 get_simulation_type - this procedure asks the user for the type of simulation
                       he wishes to run. It then sets the correct simulation
                       type and builds the appropriate input signal to
                       be used in the simulation.
```

```
   simulation_time    - the total time for the simulation
   sample_time        - time between successive samples of the input signal
   time_step_size     - time between display updates of the simulation data

 ************************************************************************/

get_simulation_type:                  procedure(simulation_time,sample_time,
                                                time_step_size);

    declare
        simulation_time              real,
        sample_time                  real,
        time_step_size               real,
        temp_simulation_type         integer;

    call clear$screen;
    call write_ln(con,@(0,'Simulations that you may run: \n\n^'));
    call write_ln(con,@(0,'     1 -  doublet dynamic check\n^'));
    call write_ln(con,@(0,'     2 -  5 degree step\n^'));
    call write_ln(con,@(0,'     3 -  5 degree step [no feedback]\n\n^'));

    call get_integer_parameter(@(0,'simulation type desired : ^'),@temp_simulati
on_type,false);
    simulation_type = low(unsign(temp_simulation_type));

    do case (simulation_type - 1);
        call simulate_doublet_input_to_model(simulation_time,sample_time);
        call simulate_step_input_to_model(simulation_time,sample_time,time_step_
size);
        call simulate_step_input_to_model(simulation_time,sample_time,time_step_
size);
    end;

end get_simulation_type;

/*######################################################################
    routines which run the entire simulation
 ######################################################################*/

/***********************************************************************
 setup_simulation - this procedure gets the simulation time, sample time
                    and time_step_size.  It then programs the timer for
                    the correct interrupt time, and determines the type
                    of simulation the user wishes to run

 parameters-
    ptr_sample_time     - pointer to the value for the sample time
    ptr_time_step_size  - pointer to the value for the time step size
    ptr_simulation_time- pointer to the value for the simulation time

 ***********************************************************************/

setup_simulation:                     procedure(ptr_sample_time,ptr_time_step_size,
                                                ptr_simulation_time);

     declare
         ptr_sample_time             pointer,
         ptr_time_step_size          pointer,
         ptr_simulation_time         pointer,
         output_string               string,
         sample_time                 based ptr_sample_time real,
         time_step_size              based ptr_time_step_size real,
         simulation_time             based ptr_simulation_time real;

     call get_time_constraints(@sample_time,@time_step_size,@simulation_time);
```

```
    absolute_sample_time = sample_time;

    call get_simulation_type(simulation_time,sample_time,time_step_size);

    call set_up_sample_timer(sample_time);

end setup_simulation;

/*****************************************************************************
 run_simulation - this procedure runs the entire simulation.  It first
                  sets up the simulation and initializes the appropriate
                  variables.  It then checks the timer to see if a next
                  value of the input signal should be sent to the 386.
                  It also determines whether the current data from the 386
                  should be stored in the simulation data.  It repeats
                  this process until the simulation has been completed

 parameters-
    ptr_sample_time     - pointer to the value for the sample time
    ptr_time_step_size - pointer to the value for the time step size
    ptr_simulation_time- pointer to the value for the simulation time

 *****************************************************************************/

run_simulation:                   procedure(ptr_sample_time,ptr_time_step_size,
                                            ptr_simulation_time);


    declare
        ptr_sample_time           pointer,
        data_storage_index        integer,
        ptr_time_step_size        pointer,
        ptr_simulation_time       pointer,
        sample_time               based ptr_sample_time real,
        time_step_size            based ptr_time_step_size real,
        simulation_time           based ptr_simulation_time real,

        time_index                integer,
        delta_time                real,
        simulation_done           byte,
        store_variables           byte;

     /* initialize the timer, input signal, and simulation variables */
     call setup_simulation(@sample_time,@time_step_size,@simulation_time);

     continue_simulation_flag = false;
     simulation_done = false;

     /* data storage index is a pointer into the simulation data array where
        we will be storing the next set of simulation data */
     data_storage_index = 0;

     /* time index is a pointer into the input signal array that tells us what
        the next value of the input signal given to the 386 will be */
     time_index = 0;
     delta_time = time_step_size;

     do while (not simulation_done);
        /* if we have gone over the total simulation time then we are done */

        if (time_index > fix(simulation_time/sample_time)) then
           simulation_done = true;

        /* see if the timer has reached terminal count yet */
        if (check_for_interrupt = true) then
           do;
```

```
            /* if so next check to see if we need to store the current
               simulation data */
            if (delta_time >= (time_step_size - sample_time)) then
              do;
                  delta_time = 0.0;
                  store_variables = true;
                  data_storage_index = data_storage_index + 1;
              end;
              else delta_time = delta_time + sample_time;

            /* send out the next data point in our input signal to the
               386 simulation program */
            call timer_interrupt_routine(time_index,data_storage_index,
                                         store_variables);

            /* increment to the next point in our input signal that will
               be given to the 386 when terminal count is reached again */
            time_index = time_index + 1;

         end;
    end;

end run_simulation;

/*###########################################################################
   routines which display data from the simulation
 ##########################################################################*/

/****************************************************************************
 get_variables_to_be_printed - this procedure asks the user which variables
                               from the simulation he wishes to display in
                               tabular format


 parameters-
    variable_info_ptr - pointer to a structure. One of the fields of
                        this structure (graph_variable) is set to true
                        if the variable should be displayed
 ***************************************************************************/

get_variables_to_be_printed:   procedure(variable_info_ptr);
    declare
        variable_info_ptr       pointer,
        variable_info           based variable_info_ptr(1) graph,
        output_string           string,
        selection               integer,
        done_choosing           byte,
        i                       integer;

    do i = 0 to (variables - 1);
        variable_info(i).graph_variable = false;
    end;

    call clear$screen;

    call write_ln(con,@(0,'Choose the variables that you wish to be printed:\n\n
~'));
    do i = 0 to (variables - 1);
       call integer_string(i+1,@output_string);
       call append_string(@output_string,@(0,'     ~'));
       call append_string(@output_string,@variable_name(i));
       call append_string(@output_string,@(2,'\n'));
       call write_ln(con,@output_string);
    end;
```

```
    call write_ln(con,@(2,'\n'));

    call integer_string((variables+1),@output_string);
    call append_string(@output_string,@(0,
                           '   print the variables you have chosen\n~'));
    call write_ln(con,@output_string);

    call write_ln(con,@(2,'\n'));

    done_choosing = false;
    do while (done_choosing = false);
        call get_integer_parameter(@(0,'number of the variable to be printed :
~')
                                        ,@selection,false);
        if (selection = (variables + 1)) then done_choosing = true;
            else variable_info(selection - 1).graph_variable = true;
    end;

end get_variables_to_be_printed;


/*********************************************************************************
 print_simulation_data - this procedure prints the simulation data in a
                         tabular format.  This data may be directed to
                         either the printer or the screen


 parameters-
    simulation_time - the total time for the simulation
    sample_time     - time between successive samples of the input signal
    time_step_size  - time between display updates of the simulation data

 *********************************************************************************/

print_simulation_data:          procedure(sample_time,time_step_size,
                                          simulation_time);


    declare
        sample_time              real,
        time_step_size           real,
        simulation_time          real,

        out                      word,
        time                     real,
        result_string            string,
        data_string              string,
        (i,j,k)                  integer,
        number_of_data_points    integer,

        variable_info(variables) graph;

    if (answer_to_question(@(0,'would you like the output to go to the printer ?
~')) = 'Y') then out = lst;
        else out = con;

    /* ask the user which variables he wants to print out */

    call get_variables_to_be_printed(@variable_info);
    call clear$screen;

    number_of_data_points = fix(simulation_time/time_step_size);

    do i = 0 to (variables - 1);
        if (variable_info(i).graph_variable = true) then
            do;
                do case i;
```

```
                    call write_ln(out,@(0,'simulation data for delta error\n~'))
;
                    call write_ln(out,@(0,'simulation data for theta out\n~'));
                    call write_ln(out,@(0,'simulation data for derivative of the
ta out\n~'));
                end;
                call write_ln(out,@(0,'--------------------------------------------------------------
------\n~'));
                call write_ln(out,@(0,'time
value\n~'));
                call write_ln(out,@(0,'--------------------------------------------------------------
------\n~'));
                time = 0.0000;

                do j = 1 to number_of_data_points;
                    call real_string(time,@result_string);
                    call append_string(@result_string,@(0,'
    ~'));

                    call real_string(simulation(i).dat(j),@data_string);
                    call append_string(@result_string,@data_string);
                    call append_string(@result_string,@(2,'\n'));
                    call write_ln(out,@result_string);

                    time = time + time_step_size;
                end;
            end;
    end;

end print_simulation_data;


/************************************************************************
 setup_graphics_display - this procedure sets up the graphics display
                          by clearing the screen, drawing the graph axes,
                          and labeling the time axes. It also returns the
                          size of the display screen and sets up the text
                          sizes

 parameters-
    maximum_x_ptr - pointer to the maximum x value of the display
    maximum_y_ptr - pointer to the maximum y value of the display
    start_time    - the starting time of the data to be displayed
    end_time      - the ending time of the data to be displayed

 ************************************************************************/

setup_graphics_display:          procedure(maximum_x_ptr,maximum_y_ptr,start_time,
                                           end_time);

    declare
        maximum_x_ptr            pointer,
        maximum_y_ptr            pointer,
        maximum_x                based maximum_x_ptr integer,
        maximum_y                based maximum_y_ptr integer,
        start_time               real,
        end_time                 real,
        text_string              string;

    maximum_x = 640;
    maximum_y = 476;

    /* draw the x and y axes */
```

```
    call set$line$color(blue);
    call line(75,0,75,480);
    call line(0,28,640,28);

    /* set the type of text we will be displaying on our graph */

    call set$text$font$index(1);
    call set$character$height(6);
    call set$character$path(0);
    call set$character$orientation(0,0,2,2);
    call set$character$spacing(1.0);

    call real_string(start_time,@text_string);
    call text(80,20,0,text_string.len,@text_string.text(0));
    call real_string(end_time,@text_string);
    call text(550,20,0,text_string.len,@text_string.text(0));

end setup_graphics_display;

/*************************************************************************
 get_variables_to_be_graphed - this procedure asks the user which variables
                               from the simulation he wishes to display as
                               graphs on the color monitor


 parameters-
    variable_info_ptr - pointer to a structure. One of the fields of
                        this structure (graph_variable) is set to true
                        if the variable should be displayed
 *************************************************************************/

get_variables_to_be_graphed:   procedure(variable_info_ptr);
    declare
        variable_info_ptr      pointer,
        variable_info          based variable_info_ptr(1) graph,
        output_string          string,
        selection              integer,
        done_choosing          byte,
        i                      integer;

    /* initialize variable_info so that no variables will be graphed
       unless the user asks for them to be graphed right now */
    do i = 0 to (variables - 1);
        variable_info(i).graph_variable = false;
    end;

    call clear$screen;

    /* display the variables that the user may graph */

    call write_ln(con,@(0,'Choose the variables that you wish to be graphed:\n\n
~'));
    do i = 0 to (variables - 1);
       call integer_string(i+1,@output_string);
       call append_string(@output_string,@(0,'      ~'));
       call append_string(@output_string,@variable_name(i));
       call append_string(@output_string,@(2,'\n'));
       call write_ln(con,@output_string);
    end;

    call write_ln(con,@(2,'\n'));

    /* ask him which ones he wants to graph */

    call integer_string((variables+1),@output_string);
    call append_string(@output_string,@(0,
```

```
    call write_ln(con,@output_string);

    call write_ln(con,@(2,'\n'));

    done_choosing = false;
    do while (done_choosing = false);
        call get_integer_parameter(@(0,'number of the variable to be displayed
: ~')
                                       ,@selection,false);
        if (selection = (variables + 1)) then done_choosing = true;
            else variable_info(selection - 1).graph_variable = true;
    end;

end get_variables_to_be_graphed;


/**************************************************************************
 get_time_duration_to_graph - this procedure asks which portion of the
                              simulation data the user wishes to display
                              It then calculates the starting and ending
                              data points to be displayed based on this info


 parameters -
    start_data_pt_ptr - pointer to the value of the starting data pt to be
                        displayed
    end_data_pt_ptr   - pointer ot the value of the ending data pt to be
                        displayed
    start_time_ptr    - pointer to the starting time of the data to be displayed
    end_time_ptr      - pointer to the ending time of the data to be displayed

 *************************************************************************/

get_time_duration_to_graph:    procedure(start_data_pt_ptr,end_data_pt_ptr,
                                         start_time_ptr,end_time_ptr,
                                         simulation_time,number_of_data_pts);

    declare
        start_data_pt_ptr      pointer,
        end_data_pt_ptr        pointer,
        start_time_ptr         pointer,
        end_time_ptr           pointer,
        simulation_time        real,
        number_of_data_pts     integer,
        start_data_pt          based start_data_pt_ptr integer,
        end_data_pt            based end_data_pt_ptr integer,
        start_time             based start_time_ptr real,
        end_time               based end_time_ptr real,

        realstring             string;

    call clear$screen;
    call write_ln(con,@(0,'the total simulation time was : ~'));
    call real_string(simulation_time,@realstring);
    call write_ln(con,@realstring);
    call write_ln(con,@(0,' seconds\n~'));

    call write_ln(con,@(2,'\n'));

    call write_ln(con,@(0,'time period to be displayed :\n~'));
    call write_ln(con,@(2,'\n'));
    call get_real_parameter(@(0,'          starting time ~'),@start_time,true);
    call get_real_parameter(@(0,'          ending time   ~'),@end_time,true);

    /* given the starting and ending times, determine the first and last
       data point in our data that we will be displaying */
```

```
                                + 1;

    end_data_pt    = fix(float(number_of_data_pts - 1) * (end_time/simulation_tim
e)) + 1;

end get_time_duration_to_graph;


/*************************************************************************
 graph_line - this procedure graphs a line on the color monitor.  The
              display is really screwed up though, because 0,0 is in the
              botton left hand corner of the screen.  That means I have
              to subtract 480 from my y coords in order to get them in the
              right place

 parameters -
    start_x - starting x coordinate
    start_y - starting y coordinate
    end_x   - ending x coordinate
    end_y   - ending y coordinate

 ************************************************************************/

graph_line:                     procedure(start_x,start_y,end_x,end_y);
    declare
        start_x                 integer,
        start_y                 integer,
        end_x                   integer,
        end_y                   integer,

        output_string           string;

    start_y = 475 - start_y;
    end_y = 475 - end_y;
    call line(unsign(start_x),unsign(start_y),unsign(end_x),unsign(end_y));

 end graph_line;


 /************************************************************************
  get_graph_sizes - this procedure determines the maximum and minimum
                    values for each variable to be displayed so it
                    can scale the graph correctly.  The user may
                    set these by hand or this procedure will do it for
                    him automatically.

  parmeters -
     variable_info_ptr - pointer to a structure that contains info about
                         each variable such as its max and min value and
                         whether it is to be graphed or not
     start_data_pt     - the starting data point to be displayed
     end_data_pt       - the last data point to be displayed

  ************************************************************************/

 get_graph_sizes:               procedure(variable_info_ptr,start_data_pt,end_dat
 a_pt);

     declare
         variable_info_ptr      pointer,
         variable_info          based variable_info_ptr(1) graph,
         start_data_pt          integer,
         end_data_pt            integer,
         j                      integer,
```

```
        textstring                    string;

     if (answer_to_question(@(0,'do you wish to resize your graphs ?~')) = 'Y') t
hen
        do i = 0 to (variables - 1);
            call clear$screen;

            textstring.len = 0;
            call append_string(@textstring,@(0,'do you wish to resize ~'));
            call append_string(@textstring,@variable_name(i));
            call append_string(@textstring,@(0,' ?~'));

            if (variable_info(i).graph_variable = true) then
               if (answer_to_question(@textstring) = 'Y') then
                do;
                    variable_info(i).max_value = simulation(i).dat(start_data_pt
);
                    variable_info(i).min_value = simulation(i).dat(start_data_pt
);
                    do j = (start_data_pt + 1) to end_data_pt;
                        if (simulation(i).dat(j) > variable_info(i).max_value) t
hen
                             variable_info(i).max_value = simulation(i).dat(j);
                           else if (simulation(i).dat(j) < variable_info(i).min_
value) then
                                    variable_info(i).min_value = simulation(i).d
at(j);
                    end;


                    if (answer_to_question(@(0,'do you wish to resize the graph
by hand ?~')) = 'Y') then
                        do;
                            call get_real_parameter(@(0,'      maximum graph val
ue : ~'),@variable_info(i).max_value,true);
                            call get_real_parameter(@(0,'      minimum graph val
ue : ~'),@variable_info(i).min_value,true);
                        end;

                    if (variable_info(i).min_value = variable_info(i).max_value)
 then
                        do;
                            if (variable_info(i).min_value = 0.0) then offset =
 1.0;
                                else offset = abs(variable_info(i).min_value * 0
 .5);

                            variable_info(i).min_value = variable_info(i).min_va
 lue - offset;
                            variable_info(i).max_value = variable_info(i).max_va
 lue + offset;
                        end;

                    variable_info(i).graph_size = variable_info(i).min_value -
                                                  variable_info(i).max_value;

                end;
         end;

 end get_graph_sizes;

 /************************************************************************
  label_graph - this procedure labels the axes of the graph with the
```

```
        of the variable at the bottom of the graph

parameters -
    variable_info_ptr - pointer to a structure that contains info about the
                        variable such as its max and min values
    values_x          - the x coordinate where the max and min values are
                        to be written on the screen
    max_val_y_ptr     - pointer to the y coordinate on the screen where the
                        maximum value for the variable should be written
    minval_y_ptr      - pointer to the y coordinate on the scrren where the
                        minimum value for the variable should be written
    name_x_ptr        - pointer to the x coordinate where the name of the
                        variable should be written
    name_y_ptr        - pointer to the y coordinate where the name of the
                        variable should be written
    color_ptr         - pointer to the color that all this stuff should be
                        written in
    var_num           - the number of the variable to be displayed

******************************************************************************/

label_graph:                procedure(variable_info_ptr,values_x,
                                      maxval_y_ptr,minval_y_ptr,
                                      name_x_ptr, name_y,color_ptr,var_num);

    declare
        variable_info_ptr       pointer,
        maxval_y_ptr            pointer,
        minval_y_ptr            pointer,
        name_x_ptr              pointer,
        color_ptr               pointer,
        variable_info           based variable_info_ptr(1) graph,
        maxval_y                based maxval_y_ptr word,
        minval_y                based minval_y_ptr word,
        name_x                  based name_x_ptr word,
        name_y                  word,
        values_x                word,
        color                   based color_ptr word,
        var_num                 integer,
        text_string             string;

    call set$line$color(color);
    call set$text$color(color);
    color = color + 1;
    if (color > 15) then color = 1;

    call real_string(variable_info(var_num).max_value,@text_string);
    call text(values_x,maxval_y,0,text_string.len,@text_string.text(0));
    call real_string(variable_info(var_num).min_value,@text_string);
    call text(values_x,minval_y,0,text_string.len,@text_string.text(0));

    /* change the y positions for the max value and min value so when we
       put on the max and min values for the next graph they wont be written
       over the max and min values for this graph */

    maxval_y = maxval_y - 12;
    minval_y = minval_y + 12;

    call text(name_x,name_y,0,variable_name(var_num).len,
              @variable_name(var_num).text(0));

    name_x = name_x + (8 * variable_name(var_num).len);

end label_graph;
```

```
graph_simulation_data     this procedure draws the graphs [illegible]
                          variables that have been recorded during the
                          simulation

parameters-
   simulation_time - the total time for the simulation
   sample_time     - time between successive samples of the input signal
   time_step_size  - time between display updates of the simulation data

***************************************************************************/

graph_simulation_data:          procedure(sample_time,time_step_size,
                                     simulation_time);


    declare
        sample_time              real,
        time_step_size           real,
        simulation_time          real,

        start_time               real,
        end_time                 real,
        start_data_pt            integer,
        end_data_pt              integer,

        number_of_data_pts       integer,
        i                        integer,
        j                        integer,
        done_graphing            byte,
        first_point              byte,

        maxval_y                 word,
        minval_y                 word,
        name_x                   word,
        color                    word,
        maximum_x                integer,
        maximum_y                integer,
        x_position               integer,
        y_position               integer,
        old_x_position           integer,
        old_y_position           integer,
        graph_step_size          integer,
        offset_x                 integer,
        offset_y                 integer,
        space_between_data_pts   integer,

        max_value                real,
        min_value                real,
        graph_size               real,

        variable_info(variables) graph;

    /* start time and end time define to portion of the simulation data
       that we will be displaying in our graph */
    start_time = 0.0;
    end_time = simulation_time;

    /* set boundaries on the portion of the screen in which we will be
       graphing and set the spacing between consecutive data points */
    offset_x = 80;
    offset_y = 30;
    done_graphing = false;
    space_between_data_pts = 1;

    number_of_data_pts = fix(simulation_time/time_step_size);
```

```
    minval_y = 40;
    maxval_y = 470;
    name_x = 80;
    call get_variables_to_be_graphed(@variable_info);
    call get_time_duration_to_graph(@start_data_pt,@end_data_pt,
            @start_time,@end_time,simulation_time,number_of_data_pts);

    call get_graph_sizes(@variable_info,start_data_pt,end_data_pt);

    call setup_graphics_display(@maximum_x,@maximum_y,start_time,end_time);

    /* determine the spacing on the screen between consecutive data points.
       if it is less than 2 pixels then condense the number of data points
       we will display */

    graph_step_size = (maximum_x- offset_x)/(end_data_pt - start_data_pt);
    if (graph_step_size <= 1) then
       do;
           graph_step_size = 2;
           space_between_data_pts = ((end_data_pt - start_data_pt)/
                                     ((maximum_x - offset_x)/2)) + 1;

       end;
         else space_between_data_pts = 1;

    color = 2;

    /* graph the variables */

    do i = 0 to (variables - 1);
         if (variable_info(i).graph_variable = true) then
             do;
                  call label_graph(@variable_info,4,@maxval_y
                                  ,@minval_y,@name_x,unsign(offset_y-20),@co
lor,i);

                  first_point = true;
                  x_position = offset_x;
                  j = start_data_pt + 1;

                  do while (j <= end_data_pt);
                      old_y_position = y_position;
                      y_position = fix(((simulation(i).dat(j) -
                                          variable_info(i).max_value)/
                                          variable_info(i).graph_size) *
                                         float(maximum_y - offset_y));
                      if (first_point = true) then
                          do;
                              first_point = false;
                              call graph_line(x_position,y_position,
                                              x_position,y_position);

                          end;
                            else call graph_line(x_position,y_position,
                                            old_x_position,old_y_position);
                      old_x_position = x_position;
                      x_position = x_position + graph_step_size;
                      j = j + space_between_data_pts;
                  end;
             end;
     end;

     if (answer_to_question(@(0,'do you wish to make some more graphs ?^'))
          = 'N') then done_graphing = true;

  end;
end graph_simulation_data;
```

```
display_simulation_results - this procedure will display the simulation
                             data in both tabular and graphical format
                             if the user desires either one

parameters-
   simulation_time - the total time for the simulation
   sample_time     - time between successive samples of the input signal
   time_step_size  - time between display updates of the simulation data
*********************************************************************/

display_simulation_results:     procedure(sample_time,time_step_size,
                                          simulation_time);

    declare
        sample_time              real,
        time_step_size           real,
        simulation_time          real;

    if (answer_to_question(@(0,'do you wish to display the simulation data in ta
bular format ?~')) = 'Y') then
        call print_simulation_data(sample_time,time_step_size,simulation_time);
    if (answer_to_question(@(0,'do you wish to display the simulation data in gr
aphical format ?~')) = 'Y') then
        call graph_simulation_data(sample_time,time_step_size,simulation_time);

end display_simulation_results;

/*####################################################################

  initialization of program routines

 ####################################################################*/

/********************************************************************
 setup_output_devices - this procedure establishes con as a pointer to output
                        info to the screen, and lst as a pointer to output
                        info to the printer

 parameters - none
 ********************************************************************/

setup_output_devices:           procedure;

    declare
        device_open              byte;

    device_open = open$connection;
    lst = lst$out;
    con = con$out;

end setup_output_devices;

/********************************************************************
 init_variables - initialization of the signal names that we will be
                  recording simulation data for

 parameters - none
 ********************************************************************/

init_variables:                 procedure;
    declare
        i                        integer;

    do i = 0 to (variables - 1);
        variable_name(i).len = 0;
```

```
   end;

    call  append_string(@variable_name(0),@(0,'theta in~'));
    call  append_string(@variable_name(1),@(0,'delta error~'));
    call  append_string(@variable_name(2),@(0,'theta out~'));
    call  append_string(@variable_name(3),@(0,'deriv of theta out~'));

end init_variables;

/*$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
   Start of Main Program
 $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$*/


    /* initialize the 80287 math chip */

    call init$real$math$unit;

    /* open a connection to the screen and to the printer */
    call setup_output_devices;

    /* initialize the names of the signals that we will be tracking during
       the simulation */
    call init_variables;

    /* tell the program running on the 386 to reset itself */
    simulation_type = end_simulation;
    continue_simulation_flag = true;

    /* run multiple simulations until the user is done */
    done = false;
    do while (not done);
        call run_simulation(@sample_time,@time_step_size,@simulation_time);
        call display_simulation_results(sample_time,time_step_size,simulation_ti
me);
        if (answer_to_question(@(0,'would you like to run another simulation ?~'
)) = 'N') then done = true;

        /* tell the simulator on the 386 to reset itself */
        simulation_type = end_simulation;
        continue_simulation_flag = true;
    end;

    /* exit the program */
    call dq$exit(0);

end main_module;
```